ACIDIC PRECIPITATION IN ONTARIO STUDY
ANNUAL PROGRAM REPORT
FISCAL YEAR 1984/1985

APIOS REPORT NO. 023/85

A.P.I.O.S. COORDINATION OFFICE
ONTARIO MINISTRY OF THE ENVIRONMENT

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PROGRAM COORDINATOR: T. G. BRYDGES

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PREFACE

The Acidic Precipitation In Ontario Study was established in 1979. The program is managed by the APIOS Coordination Office. Additional information concerning any of the activities described in this report may be obtained by contacting that Office at the following address:

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INTRODUCTION

Even though substantial improvements had been made in ambient air quality from 1970 to 1980, in the mid 1970s we became aware of damage to aquatic systems removed from local sources. We learned of the deterioration of lakes in south-central Ontario at about the same time as studies in the Adirondacks in New York State had identified acidic deposition from both distant and nearby sources as the cause for acidification of lakes in this region. Therefore, in 1979, Ontario established the Acidic Precipitation in Ontario Study (APIOS) to study the causes and effects of the long range transport of air pollutants.

The purpose of the APIOS program is to protect Ontario's environment from the damaging effects of long range transport of air pollutants, their atmospheric transport and their deposition.

The program is organized in six areas of work; emissions and atmospheric processes, terrestrial effects, aquatic effects, legal initiatives, economic studies and information services. Each program area has its own specific goals. In addition, the credibility of the scientific research is assured by a documented and operational quality assurance program.

Results of the ongoing work are used to develop and implement an emissions control program for the province.

In addition, since Ontario shares a common airshed with other political jurisdictions and since the solution to the LRTAP problem requires action by all jurisdictions involved, Ontario continues to coordinate its research and emission control efforts with other parts of Canada and the United States.

Results from Ontario's aquatic research and from other areas in North America led to the establishment of a target loading of a maximum of 20 kilograms per hectare year of wet deposition of sulphate to protect all but the most sensitive aquatic systems.

The 20 kg kilogram deposition target has been adopted by the eastern Canadian provinces and the federal government.

In order to achieve the target, the eastern Canadian provinces and the federal government have agreed to reduce SO_2 emissions to 2.3 million tonnes per year by 1994 east of the Manitoba-Saskatchewan border. In 1980, SO_2 emissions totalled 4.6 million tonnes.

As part of its commitment, Ontario will reduce its emissions by a minimum of 53% of the 1980 base case.

However, the 20 kilogram target will also require joint U.S. action.

Ontario's research will continue to add to the substantial data base which already exists and which provides a justification for control action.

Hopefully, U.S. action will be forthcoming before it is too late.

TASK #1 - ATMOSPHERIC PROCESSES STUDIES

A. Emissions Inventory

The compilation of statistics on the production of SO_2, NO_x and other pollutants serves several purposes. Trends in the emission of acid-producing gases are measured and matched with changes in deposition patterns. All of the atmospheric models require as input detailed information on SO_2 and NO_x emissions, by geographic location. Knowledge of the location and magnitude of emissions sources is also essential in planning cutbacks of acid gas emissions.

During FY 1984/85, the compilation of emissions data from 1983 was completed. The Ontario Acid Rain Emission Inventory contains up-to-date and comprehensive information on sulphur dioxide, nitrogen oxides and hydrocarbons for Ontario, as well as for North America. The estimates for the 1983 Ontario emissions of sulphur dioxide, nitrogen oxides and hydrocarbons were 1.3, 0.6 and 0.6 million tonnes, respectively. The sulphur dioxide emissions represent a very significant reduction from 1970 levels, when Ontario emissions were estimated at 3.4 million tonnes.

A detailed file of the American electric utility sector emissions was compiled for the years 1972 to 1983 inclusive. Historical trends in area source emissions for the period 1970 to 1983 were also completed.

A detailed emissions inventory of volatile organic compounds (VOC) in Ontario was completed for the base year of 1980. This inventory contains VOC species information (in excess of 160 individual compounds grouped into fourteen classes) emitted from both anthropogenic and natural sources.

B. Modelling and Meteorology Studies

i) Atmospheric Modelling

Mathematical models combine our knowledge of the movement of air masses and the scavenging and chemical transformation of pollutants during transport into a set of numerical equations. Outputs from the models can be compared to observed deposition patterns, and if the comparison shows a close agreement, we gain confidence that we have a good understanding of the causes and mechanisms involved in acid deposition. Once the models are sufficiently developed, emission reduction scenarios can be assessed by looking at resulting deposition patterns.

Two simple long range transport models, a Statistical Model and a Trajectory Puff Model have been developed. The statistical model simulates long term average deposition and air concentration, whereas the trajectory puff model simulates the same on a monthly and seasonal time scale. Both models

have been extensively evaluated, peer reviewed and applied for control strategies.

A computer program including gas phase and aqueous phase chemistry of the atmosphere has been developed, to be used in the trajectory puff model. Evaluation and application of this program is continuing. A mesoscale wind model was also developed and tested and will be used in conjunction with the trajectory puff model to study the local impacts of major point sources.

An Eulerian model, "Acid Deposition and Oxidants Model" (ADOM) is under development in cooperation with Environment Canada, the Federal Republic of Germany, the Province of Québec and the States of Minnesota and New York. This model includes three dimensional transport simulation, stratiform and cumulus cloud processes, gas and aqueous phase chemistry and rigorous treatment of wet and dry scavenging. This model will be very computer-intensive and will be applicable for episodic studies. ADOM will present an excellent numerical tool to study the critical processes contributing to acid deposition and oxidant transport and deposition. It should also be able to estimate source-receptor relationships more realistically than the simple models.

During FY 1984/85, the first working versions of ADOM were implemented. The two working versions reside at the Canadian Meteorological Centre, Dorval, Québec and the Minnesota Computer Centre, Minneapolis, Minnesota. During FY 1985/86, the model will be evaluated, using a data base of observations made during two earlier intensively monitored field studies.

ii) Meteorological Data Acquisition System

The Meteorological Data Acquisition System (MDAS) is a computerized system which collects and stores meteorological data supplied by Environment Canada from the North American network of weather stations. By analysis of pressure and wind data, it is possible to calculate the path a "parcel" of air has travelled in the past few hours or days.

An alternate type of analysis uses synoptic weather classification to infer potential contribution of regional pollution sources to acidity in precipitation in Ontario.

The MDAS system has also been used to assist Environment Canada in providing air parcel trajectories for the "acid rain" bulletins to news media in Eastern North America. Air parcel trajectory statistics were also provided to Environnement Québec for their acid rain studies in 1984.

Meteorological studies to quantify the effect of Sudbury emissions on precipitation and air quality between 1980 and 1983 were completed during 1984. The smelters in the Sudbury area were shut down for nine months in 1982 and 1983. During

that time, sulphate and nitrate concentrations in precipitation were lowered in central, eastern and southeastern Ontario, when comparing events with trajectories passing over the Sudbury area. Air concentrations in northern, central, eastern and southwestern Ontario were lower during the Sudbury emissions shut-down period relative to values for the analogous period from the previous year for Sudbury sector trajectories. Studies also indicate that the area potentially impacted by Sudbury extends in all directions from the source area, with a slight preference to the region to the north and east.

C. Deposition Monitoring Networks

The APIOS Deposition Monitoring Network consists of a series of automated samplers which monitor wet and dry deposition. The sites cover all of Ontario and include 36 stations monitoring precipitation on a 28-day basis. Of these 36, 24 are equipped with filter pack instrumentation for air concentration and dry deposition determination. In addition, there are 15 and 4 stations that sample precipitation and air, respectively, on a daily basis.

All data collected during 1982 have been published in the form of data listings, statistical summaries and interpretation reports. During 1982, all regions in central and southern Ontario received more than 20 $kg \cdot ha^{-1} \cdot yr^{-1}$ sulphate in wet deposition. The "target" loading of 20 $kg \cdot ha^{-1} \cdot yr^{-1}$ is considered to protect all but very sensitive aquatic systems from damage. On a province-wide basis, wet deposition of sulphate is four to five times higher than dry deposition. In the case of nitrate, wet and dry deposition is roughly comparable. Analysis of the data indicates a large impact due to sources outside of the province.

During FY 1984/85, a comprehensive quality assurance program was implemented, including the preparation of an overall plan, a manual and a complete audit of the field, laboratory and data management components of the monitoring program. Screening criteria are being established for data and for calculating wet deposition for North American Networks using standardized methods. This effort includes the participation of Provincial, Federal and U.S. scientists involved in monitoring and mathematical modelling studies. Thus, a high quality data set is being collected for trend analysis, mathematical model validation and source apportionment.

D. Laboratory Support and Quality Assurance

A total of 71,780 tests were performed on samples collected under Task 1 this past year. The detection limits for copper, nickel, cadmium and vanadium in precipitation samples were lowered considerably by switching the analysis to graphite furnace atomic absorption spectrophotometry.

The Deposition Monitoring group (Task 1C) continues to incorporate quality assurance activities in its network operations. The second phase audit summary prepared by Concord Scientific has reported favourably on improvements in quality control areas. As well, the Quality Assurance Manual which documents these procedures is now complete.

One very important development is that the periodic external audits which have been hitherto conducted by Concord will be supplemented by an internal auditing program for the deposition monitoring networks starting in 1985. There will be a performance audit component which will evaluate site representativeness, on-site instrumentation, sample and data collection and handling while the systems audit component will evaluate the documentation of site, sample, instrumentation and corrective action.

The culmination of the deposition monitoring group's efforts has produced 1980-81 reports on the cumulative network and a performance assessment of the event precipitation and air monitoring networks.

The fact that quality assurance also impacts on such areas as meteorological data gathering and mathematical model data validation has been discussed. The Work Group members who are involved are giving this their consideration.

TASK #2 - AQUATIC EFFECTS STUDIES

A. Limnology Studies

i) Lake and Stream Chemistry Models

The development of water chemistry models for lakes and streams is vital as a means of assessing our understanding of the acidification of the aquatic environment. This is important since it provides a tool for predicting either the effects of abatement measures or the further deterioration of impacted aquatic systems should abatement measures be delayed.

A good understanding of aquatic systems is also important in making an assessment of the size of Ontario's aquatic resource at risk due to acidification. Because Ontario has such a large number of lakes, it is not possible to conduct intensive monitoring studies on any more than a small percentage of them. The development of aquatic models and a documentation of biological effects associated with acidification will provide the basis for extrapolation of this knowledge so that predictions can be made of the effects of acidification on systems not being monitored.

A data base of the watershed and hydrological characteristics of the Dorset calibrated watersheds has been compiled. This will provide the requisite information for a model to predict the loss of chemicals from watersheds in general. The loss of total phosphorus as a function of watershed characteristics has already been successfully modelled under the Lakeshore Capacity Study and a similar approach is being used to study the loss of other chemicals, such as calcium and alkalinity.

The mass balance model describing lake chemistry underwent continuing development in FY 1984/85. The extension of the total phosphorus model to calcium, magnesium and sodium was accomplished and it successfully predicted the concentration of these elements in the eight calibrated lakes. Preliminary results of modelling pH and alkalinity in these lakes have been satisfactory.

A significant advance in modelling capability occurred by moving from numerical approximation solutions to matrix analytical solutions. Sensitivity analysis techniques which describe the amount of change occurring in model predictions as a result of fluctuations in individual model parameters have been incorporated into the lake model.

The Norwegian "Birkenes-Storgama" stream chemistry model was successfully used for simulating sulphate concentration in one of the study streams. Modifications to the model resulted in successful simulation of pH, alkalinity, cations and aluminum, as well. The model was also used to make predictions of the effects of increased or decreased sulphate deposition on stream water chemistry.

ii) Calibrated Watersheds

During 1984/85, the water chemistry data base was updated to include all data from the calibrated streams and lakes up to the end of 1984. In addition, a meteorological data base, covering the period from 1976 to 1984, was created. The atmospheric data are critical for accurate determination of water budget parameters such as evaporation, which are the foundation of much of the modelling of aquatic chemistry.

The data base of watershed and hydrological characteristics was expanded to include two more of the study lakes. These two low-alkalinity lakes will allow an extension of relationships already developed which describe water chemistry in terms of watershed characteristics.

An analysis of long term trends in water chemistry in the calibrated lakes has revealed no statistically significant changes in the pH or alkalinity of the lakes over the five to nine year duration of the monitoring period.

iii) Aluminum Chemistry

As aquatic systems acidify, the concentration of aluminum increases. This can have a significant effect, since toxicity studies have shown that it is the combination of low pH and high levels of inorganic monomeric aluminum which can be lethal to fish and amphibian species. Previous years' work has led to the development of analytical methods to determine which aluminum species are present in water.

There are several schemes available to determine aluminum speciations, but the compatibility of the schemes has not been fully assessed. During FY 1984/85, three interlaboratory comparisons of aluminum speciation methods were conducted, involving a total of six laboratories. Analytical discrepancies were identified, indicating problems in procedure at some of the laboratories. Attempts are being made to resolve the discrepancies.

Also during FY 1984/85, a colourimetric procedure for aluminum analysis using catechol violet was developed and it can be used in waters with relatively low organic matter. Work is underway to implement the method for routine aluminum analysis.

iv) Mesoscale Modelling

Detailed information on water chemistry, surficial geology and physical characteristics of watersheds for Algonquin Park has been gathered over the past several years as part of a cooperative MNR/MOE study. A water chemistry survey of an additional 154 lakes in remote areas of the Park was completed in FY 1984/85. This brings the number of lakes with all types of information needed for modelling to 458. The Ontario Geological Survey surficial geology maps were overlain with

watershed boundaries, planimetered and the percentage occurrences of surficial geology types were determined within the individual lake watersheds. Initial analysis of the data shows that water chemistry is predictable on the basis of surficial geology type. The best predictor of alkalinity, pH and major cations, however, is the elevation above sea level which seems to act as an integrating parameter for many of the geologic and physical parameters. Alkalinity decreases with increasing elevation. The relationships between water chemistry and watershed characteristics that have been developed will be useful in extrapolating to other regions of similar geologic features.

B. Biological Studies

i) Invertebrates

Stream invertebrates exhibit a wide range of tolerance to acidic conditions. Some organisms, such as mayflies, usually disappear at pH's below 6.0, while others, such as some blackfly species, can tolerate pH's below 4.5. During the 1940's, detailed studies of stream invertebrate populations in Algonquin Park were conducted by scientists at the University of Toronto. During 1984/85, five of the same sites were visited and species composition and biomass were determined using emergence traps. A preliminary analysis indicates that certain species which are intolerant of low pH have disappeared from headwater streams, while no significant changes were observed in streams whose chemistry is controlled by non-acidic upstream lakes.

Surveys of plankton communities in lakes in the Sudbury area were performed. Despite signs of chemical recovery of some of the lakes (see Task 2E), there are no signs of the plankton community recovering. It is likely that elevated metal levels in these lakes are a factor in the slow response of the plankton populations.

During FY 1984/85, an automated zooplankton counting method was developed. The system will completely replace the manual counting system and features increased accuracy and on-line data storage and retrieval.

ii) Filamentous Algae

Lake acidification produces noticeable alterations in planktonic and benthic algal populations. In particular, some forms of filamentous algae are favoured by acidic conditions. Filamentous algae can colonize extensive areas of the littoral zone of acidified lakes and may reduce fish spawning areas, as well as constitute an aesthetic nuisance.

The increase in filamentous algae growth has been observed in experimentally acidified lakes in the Experimental Lakes Area of northwestern Ontario. Work done in FY 1984/85 suggests that filamentous algae populations can be reduced significantly by lake neutralization. Algal surveys had been

performed on Bowland Lake prior to its neutralization in 1983 (see Task 2E). A detailed, whole-lake mapping of Bowland Lake in 1984 indicates that the algal coverage has been greatly reduced.

Synoptic surveys were conducted on Lake of Bays and Otter Lake, near Dorset, in response to complaints and a whole-lake algal map of Plastic Lake was constructed.

iii) Odour Production

Another change in algae that sometimes occurs in softwater and acidic lakes is a population explosion of algae that produce an intensely disagreeable odour. The organism that is responsible is Chrysochromulina breviturrita, which was first described by MOE scientists in 1978. Since then, the alga has been found in many areas of northeastern North America and reports of odour problems have come from Massachusetts and New Hampshire, as well as Ontario.

During 1984, three new cases of lake-wide odours produced by C. breviturrita were reported in Ontario. Characteristically, the odours lasted for several weeks and impaired the domestic and recreational use of lakewater. One of the episodes occurred in Lake 302, a lake in the Experimental Lakes Area which has been artificially acidified with sulphuric acid.

Research being conducted under contract at the University of Western Ontario has contributed greatly to the understanding of the nutritional needs of C. breviturrita. The alga will not grow above pH 7.0 and tolerates pH's between 4.0 and 6.9. Selenium is an unusual requirement of the alga, with best growth occurring with selenium in the 50-100 µg/L range. Work continues on the influence of inorganic carbon and the forms of nitrogen necessary for odour production.

iv) pH Change and Algal "Fossils" in Lake Sediments

The study of algae and diatom communities in acid lakes has some interesting applications. Diatoms and some types of algae (chrysophytes) leave remains in the sediment which do not decompose. By carefully characterizing the diatom or chrysophyte communities in a number of lakes over a range of pH's, a "calibration" can be developed which relates the pH to community composition. This calibration can then be applied to the chrysophyte or diatom remains in a sediment core and the pH history of the lake can be reconstructed.

Diatom populations from a series of 55 lakes in a pH range of 4.5 to 7.5 were characterized and a preliminary calibration for Ontario Precambrian Shield lakes was developed. The calibration was tested on a sediment core from a neutral clearwater lake. The analysis indicated that the lake pH had not changed for about 250 years. Similar analyses are planned for two acidic lakes in FY 1985/86.

The calibration will be extended to sediment cores from Algonquin Park and the Parry Sound area to determine the inferred rate of change in lake pH during the past several decades.

An alternative to diatom dating is the use of silicate scales from chrysophyte species. This approach looks promising, since chrysophyte species are much less numerous than diatom species, so the characterization process should be considerably simplified. The past years' efforts have been directed at clarifying the taxonomy of chrysophytes in Ontario lakes and work has begun on the development of a chrysophyte calibration.

Although time consuming, these methods are proving to be very useful in defining pH declines in lakes affected by acid deposition. Results of similar work have recently been published for lakes in Sweden, Norway and Maine. Where historical chemical data do not exist (as in Ontario), these methods are the only ones available to assess long term trends in lake pH.

C. Ground-Water Studies

i) Contribution to Lakes and Streams

FY 1984/85 was the last for the ground-water studies component of the Aquatic Effects Program. Work in Harp, Plastic and Dickie Lakes to date has included water table mapping, measurement of overburden thickness and sampling of ground water from piezometers. The conclusions reached so far are that ground water can be a source of alkalinity in lakes on the Precambrian Shield, but that the amount of ground water coming into the lakes renders it a relatively minor factor in overall chemistry in the lakes studied. Typically, lakes on the Shield have very little overburden in their watersheds, although exceptions can be found such as Harp Lake.

ii) Ground-Water Quality Inventory

A follow-up inventory of well water chemistry was conducted in the area north of Huntsville. Previous surveys had revealed that wells in this area had water with low pH.

Low pH in all of the wells tested so far is due to dissolved carbon dioxide, not acid deposition. Nonetheless, low pH water supplies can be quite corrosive and leach metals out of plumbing systems. On occasion, metal levels in excess of drinking water criteria have been measured. Elevated metal levels are usually found in water that has been in contact with the plumbing for long periods and metal levels fall rapidly as the plumbing system is flushed.

A summary report of the data collected over the past three years is in preparation.

D. Fish Studies

i) Laboratory Studies

a) Toxicity Studies

Laboratory toxicity experiments using the continuous flow diluter at Dorset were carried out at 6 pH values (4.2, 4.5, 4.8, 5.1, 5.4 ad 6.0) and up to 5 aluminum levels (0, 50, 100, 200 and 300 µg/L) on the following fish species and life stages:

Species	Life Stages
Common Shiner	fertilized egg, eyed egg
White Sucker	fertilized egg, eyed egg, sac fry
Walleye	fertilized egg, eyed egg, fry (0+)
Lake Whitefish	fertilized egg, eyed egg, sac fry, swim up fry
Lake Trout	fertilized egg, eyed egg, sac fry, swim up fry
Smallmouth Bass	eyed egg, swim up fry
Largemouth Bass	fry (0+)
Brook Trout	fertilized egg, eyed egg, sac fry, swim up fry

These experiments were all performed at a calcium level of 4.0 mg/L. The species are arranged in the above table in what was determined to be decreasing order or relative sensitivity to high hydrogen ion and aluminum concentrations, such that the Common Shiner is most sensitive. Effects at each life stage differ somewhat. Therefore, the sensitivity rating is slightly different for each life stage.

Much attention is being paid to the effects of calcium levels on pH and aluminum toxicity. This year work was expanded to include the testing of the effects of three calcium levels (4.0, 1.6 and 0.6 mg/L) on the sac fry stage of lake trout in the same pH and Al conditions as described in the previous experiments. In general, survival decreased as calcium concentration decreased, in agreement with reported findings for other fish species.

Testing was initiated to investigate the effects of spring snowmelt on spawning shoals. Pulse exposures were done for 6, 24 and 48 hours and for 5 days on the swim-up fry stage of both lake trout and brook trout. These experiments were performed at pH values from 3.8 to 4.2 and aluminum values from 0 to 1,000 µg/L, all at calcium levels of 4.0 mg/L.

In addition to these toxicity experiments, several are being conducted by the Ministry of Natural Resources. One experiment examines the effect of pH and water hardness on the survival and development of lake whitefish embryos. Two stocks of lake whitefish (one from a hard-water lake, the

other from a soft-water lake) were tested for sensitivity to low pH in waters of different Ca. Preliminary results indicate a difference in the tolerance of the two stocks, and that the sensitivity to low pH increases with decreasing water hardness. The larval lake whitefish which hatched from embryos which overwintered at pH 5.5 were less tolerant of acid pulses than those which hatched from embryos overwintering at pH 6.5.

The tolerance of overwintering young-of-the-year smallmouth bass to varying pH and aluminum levels was also examined. Smallmouth bass appear to be fairly tolerant of low pH, with mortality in long-term exposures occurring at pH 4.5 or below. Tolerance was a function of water hardness and the size and condition of the fish.

b) Avoidance Reactions

Chemical monitoring of lake trout and brook trout spawning sites indicates that during periods of snowmelt in areas of acidic deposition, incubating yolk sac fry and newly emerged fry may be exposed to toxic levels of pH and aluminum. While the observed water quality is known to threaten the survival of the sensitive life stages, little is known about the ability of salmonid fry to detect and avoid these toxic waters. If such ability exists, then it may offer stocks in acid stressed areas the means of survival under repeated "acid pulses". If fry cannot detect and avoid snowmelt, we can predict fry survival and recruitment success from a knowledge of spawning shoal chemistry.

A laboratory study is being conducted by the Ministry of Natural Resources to determine whether lake trout and brook trout fry can avoid toxic water and if so, the stage at which this ability develops. The thresholds for detection and avoidance of low pH and high Al water will be determined.

Early indications are that sac fry, particularly at the later stages of yolk absorption, can avoid otherwise lethal levels of pH and Al. The work is progressing to determine the timing of the avoidance response and the modifying effects of water temperature.

c) Fisheries Synthesis and Modelling

This is a component of the Ministry of Natural Resources Fisheries Acidification Program and is designed to synthesize existing data and capture current understanding in simple empirical models of the response of fisheries to acidic deposition. These models will be used to develop estimates of the rate and extent of fisheries resource loss due to acidic deposition.

In FY 1984/85, a project was undertaken to determine the relationship between yield of lake trout and walleye (as

estimated by biomass, harvest, catch per unit effort) in Shield lakes and lake water chemistry, having first assessed several alternative approaches to modelling incremental losses in fish yield due to acidification.

Three statistical models have been developed using data from our fisheries and chemical survey program. The results of the first model suggest 2,000 Ontario lakes are acidified and some 18,000 lakes, including a significant number of lake trout, brook trout and smallmouth bass lakes are extremely sensitive to future acidification. The second model was based on discriminant function analysis of data from a set of 173 lake trout lakes. A function, that was clearly related to acidification, was developed and then applied to survey data from over 1,200 lake trout lakes. When these results were extrapolated to the entire lake trout resource, it was estimated that lake trout are extinct in 3% of Ontario lake trout lakes. In the third model, fish species diversity was related to pH; species richness (as species number) declines with decreasing pH from pH less than 6.3. Thirty and a half percent of all lakes sampled to date have pH less than 6.3 and hence fish species richness may be limited in these lakes.

ii) Field Studies

a) Comparative Lakes Project

This project is being conducted by the Ministry of Natural Resources and the Ministry of the Environment as a field verification of laboratory derived toxicity thresholds. This will enable a comparison between toxic effects observed in laboratory experiments and population effects observed in the field. This approach permits the evaluation of hypotheses on the mechanism of extinction due to acidification and the effects of other stresses on fish populations.

Earlier work was primarily focussed on lake trout. Results show that the relative abundance of lake trout decreases at pH's below 5.5 and that, at mean summer pH below 5.6, truncated age distributions occur, indicating population loss due to persistent recruitment failure. No lake trout were caught in lakes with mean summer pH below 5.2.

During the past two years, 12 brook trout lakes and six smallmouth bass lakes were surveyed. Future work will include data collection on walleye lakes.

b) Trend Through Time Studies

The Trend Through Time Studies are designed to test models of the effect of surface water acidification on fish communities through the collection of time series data on water chemistry and biota in acidifying systems. Fifteen lakes located in the Muskoka-Haliburton-Algonquin Park area of Ontario are being

assessed. The lakes were selected to represent the most sensitive Ontario waterbodies (lake area $<$ 200 Ha; inflection point alkalinity $<$ 2 mg L^{-1} $CaCO_3$; located in the area of South Central Ontario which is receiving the highest deposition of acid - weighted mean annual precipitation pH $<$ 4.3, containing one or more of the following species: lake trout, brook trout, smallmouth bass, lake whitefish). We are attempting to link changes in the fish communities to changes in water chemistry or other stresses.

Baseline fisheries data have been collected on all 15 study lakes for at least one year. Data reports have been prepared for three study lakes and the results of small fish surveys, water chemistry monitoring, creel censuses and feeding studies on groups of study lakes analyzed and presented in technical reports.

Several special studies have been initiated to determine the cause of population anomalies or to better evaluate chemical characteristics of spawning shoals. For example, successive recruitment failure of white suckers in Westward Lake is being studied using a combination of in situ egg incubation studies, adult transfer experiments and comparison of age structure with other Shield lake white sucker populations. Similarly, potential causes of recruitment failure of both white and longnose suckers in Nunikani Lake have been examined. Studies were initiated in 1985 to establish the cause of an apparent reduced abundance of Delano Lake lake trout. Studies over the period of incubation of brook trout eggs and fry in 1983/84 and 1984/85 have demonstrated that the water chemistry on brook trout spawning shoals is highly influenced by ground water (generally higher in pH and essential ions such as calcium) and hence, likely affords some protection to developing eggs and fry from snow melt acid pulses. Toxic chemical conditions (pH 5.10, Inorganic Al 292 ugL^{-1}) measured on the lake trout spawning shoal in Sherborne Lake in 1984 are being reevaluated in 1985. Chemical monitoring is being supplemented with in situ exposures of eggs and fry and the results compared to similar bioassays on other lake trout shoals.

E. Extensive Lake Sampling

This program is carried out in cooperation with the Ministry of Natural Resources and is designed to delineate the magnitude of Ontario's aquatic resource at risk due to acidification. The results of sampling over 5,300 lakes in the province were published and a summary is shown in Tables 1 and 2.

The majority of the acidified lakes are in an elliptical area around Sudbury, stretching to the northeast and southwest of the city. However, an increasing number of acidified lakes are being identified in other areas of the province, including

Algonquin Park, Muskoka-Haliburton, Algoma and Parry Sound. Mostly, these acidified lakes are small headwater lakes, but their distance from point sources implicates long range transport of acids as the cause of acidification.

Another result of the extensive lake survey has been the identification of three acidified lakes in Pukaskwa National Park, in Northwestern Ontario. These are the first acidified lakes found in this region. They are unique in Ontario since they appear to be being acidified by a fairly low rate of wet sulphate deposition. The first year's sampling of deposition indicates that the total sulphate deposition in the area is about 16 kg/ha·yr. An analysis of the water chemistry results indicates that sulphuric acids, and not natural organic acids, are responsible for the water acidity in these lakes.

During 1981 to 1983, over 200 lakes around the Sudbury area had been sampled. Most of these lakes had also been sampled between 1974 and 1976. In 1984/85, a report describing the changes in water chemistry in these lakes was prepared. Many of the lakes close to the Sudbury smelters show signs of significant improvement related to declines in sulphur dioxide emissions. This is seen as a very encouraging result, since it demonstrates that abatement of sulphur dioxide emissions will result in tangible improvements in the water quality. The degree of improvement in the lakes in the Sudbury area was correlated with their proximity to the smelter.

F. Remedial Methodologies Development

Recognizing that lake neutralization is at best a temporary measure to delay or reverse the effects of acidification, Ontario is pursuing the development of lake neutralization expertise as a method of protecting and rehabilitating lakes. Even under the most optimistic of emission abatement scenarios, the significant reduction of acid inputs into many of Ontario's lakes is several years away. Lake liming may prove to be a feasible interim measure for the protection of important gene pools or the rehabilitation of significant sport fisheries.

In August of 1983, the first of two whole-lake neutralizations occurred. Bowland Lake was neutralized with 85 tonnes of finely powdered calcite. The limestone was applied in August by a Canso water bomber and the pH of the lake was raised from about 5.1 to approximately 6.8. Prior to neutralization, Bowland Lake water was toxic to lake trout. Yellow perch still existed in the lake in a numerous but stunted population. The indigenous lake trout and white sucker populations had disappeared in the late 1960's and repeated efforts to stock the lake had failed.

After neutralization, fingerling, yearling and adult lake trout were introduced to the lake. So far, the trout seem to be surviving and some attempted spawning was observed. The survival and reproductive success of the stocked trout will continue to be monitored.

The second whole-lake neutralization occurred in May, 1984. Trout Lake, near Parry Sound, was a low alkalinity lake, with a self-reproducing trout population. The liming of Trout Lake demonstrated no adverse biological effects associated with lake liming. No significant mortality occurred in lake and rainbow trout suspended in cages around the lake during the liming operation.

Improvements in liming technique were also made. The Bowland Lake liming used dry calcite powder and a dissolution efficiency of a little over 50% was achieved. Slurrying the calcite with a dispersant and water resulted in a dissolution efficiency greater than 90% in Trout Lake.

The lake neutralization study is a joint MOE/MNR program being conducted under contract by Booth Aquatic Research.

G. Laboratory Support and Quality Assurance

The analytical test load in support of Task 2 programs amounted to 244,246 tests. A special concern of some of these studies is continuity of analytical methodology. As with other programs, trends in chemical concentration are frequently of utmost interest, so two special studies were conducted to assess the compatibility of new analytical procedures compared to old methods.

Over 85,000 tests were completed at the laboratory in the Dorset Research Centre. The automation of that laboratory is progressing and, in the upcoming year, direct input of results from many of the automated analytical systems should result in increases in productivity.

There is a consensus that documentation of the existing procedures, highlighting those pertaining to quality assurance, will help identify project deficiencies.

The Aquatic Ecosystems Section of the Water Resources Branch, Dorset Research Center has produced a QA/QC Report describing activities which have contributed to the data quality of lake, stream and precipitation sampling.

The major effort that is still required is the writing of the Quality Assurance Plan which will provide definite requirements for all projects in detailed guideline format.

TABLE 1: Summary of the Number of Lakes in each Alkalinity Class by County or District and for Ontario

County or District	Number of Lakes in each Alkalinity Class					Total No. of Lakes Evaluated
	Acidified ($\leq$ 0 ueq L^{-1})	Extreme Sensitivity ($>$ 0 to 39.9 ueq L^{-1})	Moderate Sensitivity (40 to 199 ueq L^{-1})	Low Sensitivity (200 to 499 ueq L^{-1})	Not Sensitive ($\geq$ 500 ueq L^{-1})	
Algoma Dist.	39	96	266	130	174	705
Bruce Co.	.	.	.	.	7	7
Cochrane Dist.	2	6	10	24	203	245
Durham Co.	.	.	.	.	1	1
Frontenac Co.	.	.	1	10	63	74
Grey Co.	.	.	.	.	3	3
Haliburton Co.	6	123	152	42	33	356
Hastings Co.	.	7	61	25	56	149
Huron Co.	.	.	.	.	1	1
Kenora Dist.	.	.	88	88	101	277
Lanark Co.	.	.	.	1	38	39
Leeds Co.	.	.	.	.	32	32
Lennox & Addington Co.	.	4	26	20	39	89
Manitoulin Dist.	24	18	1	1	5	49
Middlesex Co.	.	.	.	.	1	1
Muskoka Dist.	9	98	168	11	12	298
Nipissing Dist.	18	126	420	80	2	646
Northumberland Co.	.	.	.	.	1	1
Parry Sound Dist.	18	121	196	24	3	362
Peel Co.	.	.	.	.	1	1
Peterborough Co.	.	2	9	9	42	62
Prince Edward Co.	.	.	.	.	9	9
Rainy River Dist.	.	16	155	63	41	275
Renfrew Co.	2	28	166	88	58	342
Simcoe Co.	.	.	8	2	10	20
Stormont Co.	.	.	.	.	1	1
Sudbury Dist.	83	102	135	85	118	523
Thunder Bay Dist.	4	25	131	175	251	586
Timiskaming Dist.	15	17	29	42	48	151
Victoria Co.	.	.	21	1	12	34
York Co.	.	.	.	.	2	2
Provincial Total	220	789	2,043	921	1,368	5,341

TABLE 2: Summary of the Percentage of Lakes in each Alkalinity Class by County or District and for Ontario.

County or District	Percentage of Total Number of each Alkalinity Class					Total No. of Lakes Evaluated
	Acidified ($\leqslant$0 ueq L^{-1})	Extreme Sensitivity ($>$0 to 39.9 ueq L^{-1})	Moderate Sensitivity (40 to 199 ueq L^{-1})	Low Sensitivity (200 to 499 ueq L^{-1})	Not Sensitive ($\leqslant$500 ueq L^{-1})	
Algoma Dist.	5.5	13.6	37.7	18.4	24.7	705
Bruce Co.	.	.	.	.	100.0	7
Cochrane Dist.	0.8	2.5	4.1	9.8	82.8	245
Durham Co.	.	.	.	.	100.0	1
Frontenac Co.	.	.	1.4	13.5	85.1	74
Grey Co.	.	.	.	.	100.0	3
Haliburton Co.	1.7	34.6	42.7	11.8	9.3	356
Hastings Co.	.	4.7	40.9	16.8	37.6	149
Huron Co.	.	.	.	.	100.0	1
Kenora Dist.	.	.	31.8	31.8	36.5	277
Lanark Co.	.	.	.	2.6	97.4	37
Leeds Co.	.	.	.	.	100.0	32
Lennox & Addington Co.	.	4.5	29.2	22.5	43.8	89
Manitoulin Dist.	49.0	36.7	2.0	2.0	10.2	49
Middlesex Co.	.	.	.	.	100.0	1
Muskoka Dist.	3.0	32.9	56.4	3.7	4.0	298
Nipissing Dist.	2.8	19.5	65.0	12.4	0.3	646
Northumberland Co.	.	.	.	.	100.0	1
Parry Sound Dist.	5.0	33.4	54.1	6.6	0.8	362
Peel Co.	.	.	.	.	100.0	1
Peterborough Co.	.	3.2	14.5	14.5	67.7	62
Prince Edward Co.	.	.	.	.	100.0	9
Rainy River Dist.	.	5.8	56.4	19.6	14.9	275
Renfrew Co.	0.6	8.2	48.5	25.7	17.0	342
Simcoe Co.	.	.	40.0	10.0	50.0	20
Stormont Co.	.	.	.	.	100.0	1
Sudbury Dist.	15.9	19.5	25.8	16.3	22.6	523
Thunder Bay Dist.	0.7	4.3	22.4	29.9	42.8	586
Timiskaming Dist.	9.9	11.3	19.2	27.8	31.8	151
Victoria Co.	.	.	61.8	2.9	35.3	34
York Co.	.	.	.	.	100.0	2
Provincial Total (number of lakes)	4.1 (220)	14.8 (789)	38.3 (2,043)	17.2 (921)	25.6 (1,368)	5,341

TASK #3 - TERRESTRIAL EFFECTS STUDIES

A. Vegetation Studies

i) Lichen and Moss Study

Lichens obtain a substantial portion of their nutrients from the air and from precipitation. Because of this, they have been used as air quality indicators, since their chemistry reflects concentrations and deposition of atmospheric elements.

Lichens and moss have been obtained and chemically characterized from approximately 50 locations across Ontario. Variability in chemical composition at given sites and during the growing season have also been determined. Interspecific comparison of chemical content between two lichen species has revealed close similarities, while significant differences have been observed between lichens and moss.

Metal levels in lichens are strongly influenced by their proximity to major sources of metal-contaminated particulates. The sulphur content of lichens exhibits a south-to-north decrease in concentration. The elemental composition of wet deposition can account for only part of the variability seen in the chemical content of lichens. Gaseous and airborne particulate materials and perhaps the chemistry of the substrate, may also be required to account for the remaining variability.

Other activities under the Lichen and Moss Study included inventories of species at three biogeochemical sites (see Task 3C) and the establishment of photometric plots of lichens to determine growth rate.

ii) Experimental Vegetation Studies

These studies are designed to assess the impact of acid deposition and associated air pollutants on commercially important crop species.

FY 1984/85 saw the first experiments conducted in the Mobile Rain Exclusion Canopies. These are greenhouse type canopies, installed on tracks, which can be moved over crops during rain events and retracted when the rain events are finished. Under the canopies are a grid of nozzles which apply synthetic rain of differing chemistries to crop plants. The synthetic rain is applied in the same amount and at the same time as the rain event outside. At the end of a rain event, the canopies retract, leaving the crops exposed to ambient conditions.

All phases of the exclusion canopy operation are automated, from detection of a rain event, deployment of the canopies, mixing and application of the treatments and retraction of the canopies. Another feature of the system is a set of blowers and pillows which can be deployed between rows of crops. If ambient air monitors detect elevated levels of SO_2, O_3 or NO_x, the pillows are inflated and produce streams of pollutant filtered air around the crops, thereby reducing the ambient air concentration of the pollutants in the vicinity of the plants. In the future, the pillow system could be used to "spike" the surrounding air with increased concentrations of pollutants, so that the interaction between acid deposition and air pollutants could be studied.

During FY 1984/85, the system was operated to correct any faults. The system was used to study two cultivars of radish and one soybean cultivar (var. Bicentennial). The crops were exposed to pH treatments between pH 3.0 and pH 5.6. There were no significant treatment effects on radish root yield.

Similarly, acid rain had no measurable effect on the soybeans, measured as number of seeds per pod or number of pods per plant. Some foliar injury was observed on soybean plants exposed to pH 3.0 rain, but there was no apparent yield reduction in response to the injury.

In addition to the exclusion canopy experiments, seedling establishment, foliar injury and shoot and root biomass as a function of acid rain acidity were assessed for a number of crops in indoor rain simulation chambers. Four cultivars each of cabbage, barley, cucumber and corn were tested during FY 1984/85.

As with previous crops tested, response varied significantly from crop to crop and cultivar to cultivar. In general, no deleterious effects on plant biomass were documented until rain acidity was pH 3.0 or below.

B. Soil Studies

i) Baseline Studies

A report on the baseline soil data collected in FY 1980/81 was completed during FY 1984/85. This report tabulates the analytical results on over 3,000 soil samples from 250 sites around Ontario. The study was the first province-wide survey of non-agricultural soils, using standardized modern analytical techniques. The report will form the basis of planned re-surveys to document any changes in soils that may be attributable to acid deposition.

ii) Soil Variability Study

The ability to detect chemical changes in soil caused by acidic precipitation is limited by the chemical variability of the soil. A soil variability study is being conducted to examine the spatial and seasonal variation of soil characteristics at the two southern Ontario biogeochemical sites. The results of this study will be crucial in differentiating between changes in soil chemistry which are due to natural variation and changes which might be attributable to acidic precipitation.

The sampling portion of this study is now complete. Preliminary evaluation of the data indicate that base saturation and pH vary considerably during the seasons. In addition, pH can vary by up to 1.4 units within a single sample plot at any given time.

iii) Soil Column Experiments

An experiment designed to monitor changes in soil and leachate chemistry was terminated. Three soil types, divided into horizons and combinations of horizons, had been leached for 105 weeks with simulated acid rain of varying pH.

The experiment demonstrates the retention of virtually all of the sulphate by lower column horizons. In contrast, calibrated watershed studies in Ontario and elsewhere have shown that sulphate acts as a conservative substance; it is not retained to any great degree in watersheds. This suggests that either water in soil which comes into contact with lower horizons represents an insignificant portion of the water budget of these systems or that the conditions of the experimental columns differ significantly from those found in the field.

C. Biogeochemical Studies

The purpose of the biogeochemical studies is to measure the input, export and internal cycling of nutrients and metals in forested ecosystems. The calibrated watershed studies under Task 2 are designed to construct nutrient and metal budgets for lakes and streams; the biogeochemical studies extend these budgets to the terrestrial watershed.

The basic components of the measurements at the biogeochemical sites include:

Deposition: wet deposition amounts and composition are collected with sampling and analytical methodology compatible with the cumulative deposition network (see Task 1C).

Throughfall: wet deposition falling through the forest canopy is collected for comparison with chemistry of deposition which does not contact the canopy. Collections are made under all major tree species in each watershed.

Stemflow: precipitation flowing down tree trunks is collected for comparison with deposition. Again, major tree species are represented.

Soil water: collection of rainfall as it seeps through the various soil horizons is accomplished with non-tension lysimeters.

Groundwater: standpipes and piezometers are used to collect shallow and deep groundwater. Observation wells have been drilled to allow measurement of water table depth.

Forest stand inventories: to determine tree species occurrence, basal area of standing crop and forest stand types on the watershed.

Biomass: complete trees (leaves or needles, branches, stem, roots) from major species at each site have been sampled to determine mass and composition.

Soils: soil profiles have been sampled throughout each site and chemically characterized.

Forest soil surveys: soil types at each watershed have been determined via surveys and similar soil morphologies have been mapped.

Litterfall: leaves, needles and twigs shed each year are intercepted under major species for mass and chemical analysis.

Litter decomposition: litter bags containing foliage from major tree species are used to monitor decomposition rate and gain or loss of bioelements.

There are four watersheds being intensively studied under this program. The two southern sites are in the Harp and Plastic Lake watersheds and receive wet sulphate deposition of approximately 30-35 kg/ha·yr.

One of the northern sites is at High Falls, near Sudbury. This site receives about 20 kg/ha·yr wet sulphate deposition. The other northern site is in the Hawkeye Lake watershed, near Thunder Bay. The wet sulphate deposition rate at Hawkeye Lake is about 10 kg/ha·yr. These biogeochemical study areas will be discussed separately.

Hawkeye Lake

The Hawkeye Lake site is unique in that it is the only study of this nature being conducted in an area that receives relatively low levels of acid deposition. The results from this site are of importance as a control, not only to the other A.P.I.O.S. biogeochemical sites, but also to international studies. The acid rain issue has served to highlight many gaps in our understanding of the environment and one of the larger gaps is nutrient and elemental budgets in "background" or relatively uncontaminated areas. The results from this site should help fill some of those gaps.

A comparison of incident rainfall and throughfall chemistry was completed. The topographic survey of the watershed was completed and a hydrological survey to determine water table levels was begun. Tree biomass estimates were finished for the major species on the watershed.

Also completed during FY 1984/85 was a soil survey of the watershed. The construction of a soil map of the watershed awaits the completion of chemical analyses.

High Falls

The High Falls watershed is located 40 km west of Sudbury. It represents a site intermediate in deposition and climate between the two southern biogeochemical sites and the northwestern site.

Deposition loadings for major and minor rainfall components were calculated for 1983 and 1984 and summarized on an event and monthly basis. Work began on establishing the interrelationships between the chemistry of the incident rainfall, throughfall, stemflow and shrub layer throughfall. The mass transfer of major elements, nutrients and trace metals associated with litterfall was also calculated.

As with the other sites, representatives of major tree species have been destructively sampled, including roots, bole, branches and leaves. The weight of each of the tree parts was recorded and related to the diameter at breast height, so that estimates of total mass can be made from diameter measurements. Once the elemental analysis of subsamples from each tree are completed, elemental storage in trees on the watershed can be calculated.

Plastic and Harp Lakes

These two biogeochemical sites are situated on watersheds near Dorset. The lakes have been monitored for a number of years as part of the Calibrated Watershed Study (see Task 2.A.ii).

The southern biogeochemical sites have been in operation one year longer than the northern sites.

During FY 1984/85, the soil survey of the Harp Lake watershed was completed and a preliminary soil map for the Plastic Lake watershed was under revision. These maps, when combined with data on soil chemistry, horizon depth and bulk density, will form the basis for total soil nutrient and element storage in the watersheds.

Element and nutrient storage in trees will be estimated from the results of analysis of samples from whole trees. The destructive sampling of whole trees representing secondary species was accomplished last year. The results from earlier analyses on the major tree species from the watersheds were also compiled.

Sampling of incident precipitation, throughfall, litterfall and litter decomposition is continuing.

Data reduction of throughfall analyses continued, comparing chemical changes in rainfall after contact with different tree species.

D. Forest Productivity and Decline Studies

i) Maple Decline Study

In the spring of 1984, numerous complaints were received from the Ontario Maple Syrup Producers Association about decline or dieback in woodlots being managed for maple syrup production. A program to study the problem was initiated in 1984 and included examination of eight woodlots which were intensively sampled. Seven of these were in the Muskoka/Parry Sound districts of central Ontario and one site was near Thunder Bay, in northwestern Ontario which has low levels of acid deposition and other air pollutants. Permanent observation plots were established at all sites, tree condition was assessed and samples of soil, roots and vegetation were taken for chemical analysis. Radial increment cores and discs from felled trees were also taken for growth and stem analysis.

The soil results indicated that the sandy soils in the Muskoka/Parry Sound area had low cation exchange capacities and high levels of soluble aluminum. The poor base status of these soils may contribute to the decline syndrome. Higher amounts of aluminum were found in the fine roots of declining trees compared to healthy trees. Another contributing stress may be tapping; decline appeared to be higher in tapped trees, compared to those which are not tapped for sap.

The declining trees also had a high incidence of _Armillarea mellea_ (honey fungus). Studies of a similar decline in areas

of Québec have indicated that this fungus is not a cause of the decline. The fungus attacks trees which are already dying back and may accelerate the later stages of decline.

Outbreaks of forest tent caterpillar in 1976 and 1977 and spring droughts in 1976, 1977 and 1983 have also contributed to the decline of sugar maple trees.

The results of the stem analyses will be used to compare growth rates between tapped and untapped maples and between the southern and northern sites. Of particular interest will be comparison with the chemical and growth anomalies which characterize the European forest decline phenomenon. One significant difference in Ontario from the European situation is the predominance of tree decline of deciduous trees. In Central Europe, conifers appear to be much more severely affected than deciduous trees.

ii) Tree Growth Study

Concern has been raised by studies in the United States and Europe that acid deposition and other air pollutants may play a role in the reduction of tree growth rates.

This tree growth study is being conducted by the University of Toronto's Faculty of Forestry with APIOS funding. It is a continuation of a study which began in 1962.

Originally, trees were tagged and measured on a number of lots in the vicinity of Dorset. The trees were remeasured in 1972 and again in 1983 and 1984. In addition to the measurements, a number of trees have been cut down to determine growth patterns from the tree rings. The stem analysis will permit the development of relationships between tree measurements in the woodlots and the growth pattern revealed by the stem analysis.

iii) Dendrochronology and Hardwood Decline Studies

These are two studies that were in the planning stages in FY 1984/85. The dendrochronology study is designed to determine whether a widespread decline in tree growth rate is occurring in southern Ontario. Such a decline has been reported for areas in the eastern United States that have high levels of atmospheric pollutants and a similar decline occurred in West Germany prior to the widespread die-back syndrome affecting much of Germany's forests today.

The province-wide hardwood decline survey will attempt to document the extent of decline in maples, ash, birch and beech in Ontario. Some informal surveys of park managers and Ministry of Natural Resources regional staff indicated that unusual decline of several hardwood species is occurring in

some areas. MOE studies have confirmed this in the case of maple trees in the Muskoka/Parry Sound area (see 3.D.i)). This new study will assess the problem over a wider area.

E. Laboratory Support and Quality Assurance

A total of 112,484 tests were performed in support of Task 3 studies during FY 1984/85.

Several methodology changes occurred during the year. These included the analysis of stemflow samples for metals by inductively coupled plasma-mass spectrometry. A method for the determination of sulphate adsorption on soils was also developed.

The Terrestrial Effects Work Group and Technical Subcommittee now have quality assurance representation at each meeting. Members of the technical subcommittee have been charged with documenting the quality assurance concerns associated with their projects in preparation for a future meeting devoted to quality assurance and eventually completing a suitable documentation package.

TASK #4 - SOCIO-ECONOMIC INVESTIGATIONS

A. Damages and Benefits

Available data on fish populations and lake uses were assembled for Ontario lakes which are in the "Acidified" and "Extremely Sensitive" categories of the Acid Sensitivity Classification System. The objective of this exercise was to determine whether it would be possible to assess the relative importance of these lakes to people. If this can be done, specific lakes which should be protected (e.g. limed) can be identified and a better idea of the potential damages that might be caused by further acidification can be obtained.

It was postulated, for example, that those lakes inhabited by game fish were more important to society than those which did not have game fish. Moreover, larger lakes were postulated to be more important than smaller lakes. Other characteristics which were postulated to be indicators of relative importance include access, number of cottages on the lake, average depth and previous or current angling activity.

However, data on these indicators were not available on the MNR combined lakes data-base so that meaningful comparisons could not be made with these data. Further inquiries indicated that MNR Regional and District Offices would have a great deal more use and angling data on many of the lakes but that such information would not be on computer files.

Further work is being contemplated to conduct a more detailed assessment of lake use and to obtain relevant information from MNR Regional Offices.

During the fiscal year, efforts were made to obtain aquatic, botanical and corrosion models or dose-response information from APIOS Work Groups, from other Ministries and from the literature. However, the acid deposition research community has not yet produced models or dose-response relationships that command wide agreement and support among workers in these areas. Consequently, the bio-physical effects of acid deposition and their economic or social implications can be estimated only with a great deal of uncertainty.

B. Costs of Abatement and Mitigation

Although internal work by staff to estimate abatement cost functions and to assess the impacts of abatement costs on particular firms has proceeded, no contract work in this sub-Task has been undertaken during the fiscal year.

C. Strategy Development and Evaluation Tools

To date, Screening Model analyses have employed long range transport coefficients from the MOE "Statistical Model". Transport coefficients from the MOE "Lagrangian Model", which

produces coefficients on an annual basis, for the years 1979, 1980 and 1981 have now also been used in Screening Model runs. Comparisons were made of the two sets of transport coefficients (i.e. Statistical and Lagrangian). Moreover, Screening Model results that were produced using each type of coefficient were then compared with deposition data for the three years noted above.

Preliminary results indicate that the Lagrangian coefficients provide more accurate representation of the actual transport of acid-forming pollutants than do the Statistical Model coefficients. Removal requirements for U.S. sources increase when Statistical Model coefficients are replaced by Lagrangian transfer coefficients. Data for three years have been assembled (1979, 1980 and 1981), but many more years' data would be required to obtain average transport coefficients that could be used with confidence.

A final report of this study will be presented in FY 1985/86.

TASK #5 - LEGAL INITIATIVES

A. Provincial Initiatives

Since 1980, Ontario has believed that there was sufficient evidence to implement SO_2 controls immediately while research continues to evaluate the benefits of these controls. As a result, Ontario was the first jurisdiction in North America to mandate emission controls based solely on the effects of long range transport of air pollutants, as distinct from local ambient air quality standards.

In July, 1980, Inco was required to cut SO_2 emissions from its Copper Cliff smelter from 2,366 to 1,769 tonnes per day by December 31st, 1982. In February, 1981, Ontario Regulation 73/81 was enacted limiting Ontario Hydro's annual SO_2 emissions to 390,000 tonnes by 1986 and 260,000 tonnes by 1990.

In the absence of an acid rain agreement with the United States, the federal government and the eastern Canadian provinces decided in March, 1984, to take unilateral action and reduce sulphur dioxide emissions to a ceiling of 2.3 million tonnes by 1994, a 50% reduction from the 1980 base case year.

More recently, on February 5th, 1985, the federal government and the eastern provinces agreed to a series of steps to achieve the first 1.9 million tonnes of this reduction and committed to determining the allocation of any further reductions in sufficient time to achieve the 1994 objective. Ontario will reduce its emissions by 53% as part of its commitment.

Ontario is reviewing the control orders and regulations currently in place to determine future control actions required to meet the 1994 commitment.

B. International Initiatives

Ontario has repeatedly been concerned that, in spite of the fact that under the Memorandum of Intent both Canada and the United States agreed to enforce existing laws and regulations in a way which is responsive to the problems of transboundary air pollution, the United States Environmental Protection Agency continues to propose revisions in State Implementation Plans (S.I.P.s) under Section 110 of the U.S. Clean Air Act which would lead to increases in allowable sulphur dioxide emissions from coal-fired power plants.

Therefore, Ontario has undertaken to participate in any U.S. proceedings which could affect, as a result of long range transport, the province's environmental quality. Ontario's efforts have been directed at encouraging the U.S. E.P.A. Administrator to disapprove any S.I.P. revisions which would

result in any increase in permissible emissions of SO_2 in the U.S. A summary of Canada's activities in this area since 1981 is provided in Table 3.

Of special interest during FY 1984/1985 was the reversal of a 1983 decision made by the Michigan Air Pollution Control Commission because of its potential economic and social impacts. The history is as follows.

On November 28, 1983, the Michigan Air Pollution Control Commission held a Public Hearing to consider the Consumers Power Company request to delay bringing its J. H. Campbell and B. C. Cobb power plants into compliance with the Michigan "one percent sulphur in fuel" rule. The Ontario Ministry of the Environment submitted both verbal and written presentations in opposition to this request. The Commission, after the Public Hearing ended, decided to deny the Company's request.

The Company subsequently announced that it would be forced to invoke 'force majeure' to terminate its high sulphur coal contract with Sunnyhill mine owned by the Peabody Coal Company. The E.P.A. was requested by House Energy and Commerce Committee Chairman J. Dingell and Ohio Representative Clarence Miller to implement Section 321 of the U.S. Clean Air Act to undertake an employment impact probe. The results of this study, the first Section 321 probe, showed that enforcing the law would throw 520 Ohio miners out of work. Therefore, the Michigan Air Pollution Control Commission, in a reversal of its previous ruling, in June of 1984, granted a three year extension to the Consumers power Company for its J. H. Campbell plant.

Throughout FY 1984/1985, Ontario continued to monitor developments in the suit filed by the States of New York and Pennsylvania and several environmental groups under Section 126 (Interstate Pollution) and Section 115 (International Pollution) of the U.S. Clean Air Act.

This petition filed against the U.S. Environmental Protection Agency requested that i) the E.P.A. Administrator issue a final decision on the Section 126 petitions filed in June of 1981 and ii) the Administrator give notice to the Governors of States whose air pollution endanger the health and welfare of Canada to revise their S.I.P.s to prevent or eliminate harm.

On December 10, 1984, the E.P.A. announced its decision to deny the Section 126 petitions since it determined that the States did not adequately support their claims of injury. An appeal is under consideration.

At the end of FY 1984/85, the court had not taken a decision concerning the Section 115 petition.

The most recent international action was the appointment in March of 1985 by Prime Minister Mulroney and President Reagan of two high level envoys who were charged with the responsibility of preparing a report which is to review the options available to resolve the problem and to recommend a preferred option.

Table 3

Interventions by the Province of Ontario

Date	Intervention	Status
March 12, 1981	A legal intervention was filed with the U.S. Environmental Protection Agency which requested the EPA to reject proposals from six states for a relaxation of emission limits governing 18 power plants in Ohio, Michigan, Illinois, West Virginia and Tennessee.	
March 27, 1981	The previous intervention was expanded to include two large power plants near Cleveland, Ohio.	As of July 1985, the status of the 20 SIPs was: No action 1 Decision Pending 10 Proposed disapproval 1 Approved 8.
June 19, 1981	Ontario appeared at the U.S. EPA Section 126 Hearings held in Washington D.C. in support of the States of New York and Pennsylvania in their petition concerning Interstate Pollution.	A legal suit has been filed by several States and environmental groups. EPA denied the petition in December 1984.
October 7, 1981	Before the Indiana Air Pollution Control Board to oppose an increase in SO_2 emissions for the Clifty Creek Generating Station to 7.52 lbs of SO_2 per million B.T.U.	Approved by the State of Indiana.

Date	Intervention	Status
June 30, 1982	Before the Michigan Air Pollution Control Commission in opposition to the Detroit Edison request to delay bringing its Monroe Power Plant into compliance with the State of Michigan "one percent or equivalent sulphur in fuel" rule.	Denied by the State of Michigan.
February 1983	A letter was submitted to the Indiana Air Pollution Control Board in opposition to the proposed sulphur dioxide emissions limit increase from 6.0 lbs of SO_2/MMBTU to 7.11 lbs for the Indianapolis Power and Light Generating Station in the Pike County Air Quality Basin.	Approved by the State of Indiana.
May 10, 1983	A letter was submitted to the U.S. E.P.A. in opposition to its proposed approval of a request by the Indiana Air Pollution Control Board to relax the state enforceable SO_2 emission limit for the Indiana-Michigan Electric Company Breed Plant from 6.0 lbs/MMBTU to 9.57 lbs/MMBTU.	Approved by the U.S. E.P.A.
November 28, 1983	Before the Michigan Air Pollution Control Commission in opposition to the Consumers Power Company request to delay bringing its J.H. Campbell and B.C. Cobb Power Plants into compliance with the Michigan "one percent or equivalent sulphur in fuel" rule.	Denied by the State of Michigan.
June 14, 1984	A letter was submitted to the Michigan Air Pollution Control Commission in opposition to the Consumers Power Company's second request to delay bringing its J.H. Campbell Power Plant into compliance with the Michigan "one percent or equivalent sulphur in fuel" rule.	Three year extension granted by the Commission in order to protect coal miners jobs at the Peabody Coal Company's Sunnyhill Mine.

TASK #6 - PUBLIC RELATIONS INITIATIVES

A. Provincial Initiatives

During FY 1984/85 work proceeded on the updating of several Fact Sheets on Acid Rain, the Acid Sensitivity Survey, the Case Against the Rain Brochure and the acid rain videotape.

The Fact Sheets are distributed in response to written and verbal requests for information on acid rain. These requests still appear to be increasing in number and the understanding of the issue is also growing.

Audiovisual aids such as the film "Crisis in the Rain" are used repeatedly for acid rain events throughout the province and by Ministry staff in response to requests for speakers from environmental and other public interest groups, especially Cottagers' Associations.

Therefore, the preparation of up-to-date material on this subject will continue to be necessary while our research provides us with an expanded knowledge base and while the government's actions to address the problem are ongoing.

B. United States Initiatives

Public opinion polls in the U.S. continue to indicate an increasing awareness of the issue as well as support for more controls despite the concomitant increase in electricity rates.

The U.S. Administration, however, maintained its position of enhanced research throughout FY 1984/85 and refused to consider any acid rain controls.

Our activities in the U.S. included continued showings of our acid rain film through the Consulate Offices and distribution of our brochure and Fact Sheets on the issue when the opportunities arose.

In addition, Ontario co-hosted two tours in September 1984: one for U.S. journalists and one for Canadian-U.S. Foundations. The journalists' tour resulted in several articles appearing in the U.S. media on Canada's perspective of the acid rain issue. The Foundations' tour resulted in active interest in the funding of acid rain projects by several of these groups.

The updating of our written material and audiovisual aids will continue to assist us in presenting our position in the United States.

SUMMARY

As of the end of FY 1984/85, the APIOS program has contributed to our understanding of the acid rain problem in Ontario and allowed the following conclusions to be reached:

- A sulphate wet deposition rate of 20 kg ha^{-1} yr^{-1} is currently exceeded in all of central and southern Ontario.

- The sulphur dry deposition rate is about one-quarter of the wet deposition rate on a province-wide basis.

- The contribution of nitrates to acid loadings in the province is comparable to that of sulphates.

- Much of the atmospheric deposition of acidifying substances is due to sources to the south of the province. Meteorological analysis and mathematical modelling indicate that the large smelters at Sudbury, for example, contribute a relatively small portion of the total atmospheric deposition of acidity and sulphates at receptor areas such as Muskoka-Haliburton. At receptor areas in southern Ontario, near the Canada-U.S. border, trajectory analysis shows that more than half of the sulphur wet deposition is associated with air parcels coming from the direction of Indiana, Ohio and Pennsylvania.

- The sulphur dioxide emissions in Ontario have been significantly reduced since 1970 (for example, annual emissions in 1970 were 3.4 million tons; in 1983, they were 1.3 million tons). Moreover, in 1983, Ontario's emissions of sulphur and nitrogen oxides constituted approximately 6% and 4% respectively of the eastern North American total.

- Statistical and trajectory mathematical models describing long-range transport and acidic deposition have been completed and peer-reviewed and extensively applied in control strategy studies by the Ministry of the Environment. The models indicate that contribution of U.S. sources to wet sulphur deposition at Muskoka and southern Québec are 50% and 30% respectively.

- Model results indicate that reducing SO_2 from Canadian sources alone will not enable us to meet the target of 20 kg/ha·yr of wet sulphate deposition at all sensitive receptors in Canada. U.S. SO_2 sources also need to be controlled if this target is to be met at all sensitive receptors in Canada.

- In central Ontario, acidic deposition derived from anthropogenic SO_2 emissions is the primary causal factor in recent lake acidification and a reduction in the anthropogenic emissions affecting this area will result in a decrease in lake acidity.

- Short-term acidification (that is, the reversible loss of alkalinity resulting from episodes or events such as snowmelt or storms) is a commonplace occurrence in the Precambrian part of southern Ontario. After natural dilution is accounted for, sulphuric acid is usually the major cause of short-term acidification, although nitric acid is, in a few isolated cases, more important.

- Long-term acidification (that is, the gradual decline in alkalinity measured on an annual basis) is occurring very slowly with little or no measurable change observed in lakes and streams studied over five to nine years. The time-scale for acidification can probably be measured in decades.

- Sulphate has become the dominant anion in almost all waters in Precambrian southern Ontario.

- Reductions in lake acidity follow reductions in SO_2 emissions within a short time frame.

- Organic acids contribute to the acidity of some lakes and streams but do not contribute significantly to short-term acidification and are not, in general, a major factor in the acidification process.

- In addition to strong acids, substantial amounts of trace metals are supplied to lakes and catchments via long-range atmospheric transport. Lead, cadmium and zinc are of particular concern, with most lead of anthropogenic origin (fuel combustion) averaging about 700 kg km^{-2} over southern Ontario.

- In a survey of approximately 4,500 Ontario lakes, it was found that 4.2% were acidified (alkalinity < 0 μeqL^{-1}) and a further 16.7% were extremely sensitive to acidic deposition (alkalinity > 0 μeqL^{-1} and < 40 μeqL^{-1}).

- The effects of acidification on aquatic biota are primarily a result of the toxic effects of hydrogen ion and inorganic monomeric aluminum.

- Early life stages of several amphibians are affected by H^+/Al concentrations that are observed in many lakes, streams and ponds.

- There are no apparent effects of acidification on either the zooplankton or macrophyte populations of lakes other than those in the Sudbury area. Some benthic stream invertebrates (mayflies, chironomids) are affected by observed H^+/Al levels, while others (caddisflies, blackflies) are not.

- Phytoplankton community structure is very different in acidic lakes (i.e. a much higher proportion of dinoflagellates which are not likely very food-chain functional). Phytoplankton biomass is not altered directly by acidification but may be indirectly affected by nutrient availability.

- The odour producing species <u>Chrysochromulina breviturrita</u> has been shown in field and laboratory studies to grow well over a pH range of 4.5 to 6.9.

- Some species of filamentous algae forming large masses in shoreline areas of lakes have been shown in laboratory and field studies to grow best at low pH. Although data are still preliminary, growth appears to be enhanced by acidification and reversed by neutralization.

- According to laboratory experiments, the sensitivity of the major species of fish in southern Ontario waters to strong acid and aluminum follows the sequence: common shiner > white sucker > walleye > lake whitefish > lake trout > smallmouth bass > brook trout. The first five of these species are affected in the laboratory at concentrations that are observed in lakes and streams.

- Recent improvements in water chemistry coincident with the reduction of emissions from Sudbury area smelters and the resumption of recruitment by some fishes indicate that habitat losses can be reversed if emissions are reduced.

- In a survey of approximately 55% of Ontario's 2,218 lake trout lakes, it was found that 6% were acidified (alkalinity $< 0\ \mu eqL^{-1}$) and 6.3% had pH levels < 5.5, a level of pH below which lake trout populations do not recruit successfully.

- Fish species richness (as species number) was found to decline with decreasing pH from pH < 6.3. Thirty and a half percent of all lakes sampled have pH < 6.3 and hence may be limited in species richness by acidity.

- The results of simulated acid rain experiments with agricultural crops illustrate that plant response to simulated acid rain treatments is not only species dependent but also strongly cultivar dependent. Rainfall pH between 3.0 and pH 4.2 may have a negative effect, a positive effect or no effect on plant growth. Results have also indicated that plant response to simulated acid rain treatments is dependent on several factors:

  a) rain characteristics (treatment application rate and duration of event);
  b) disease and pests;

c) environmental conditions (high temperature, drought); and
d) interactive stress from air pollutants (ozone, sulphur dioxide and nitrogen oxides).

° There are elevated sulphur levels in lichen and moss tissue in southern Ontario. There is also a paucity of lichens in southern Ontario which can be ascribed to pollution and habitat disturbance.

° Natural acidic soils (i.e. podzolic) are not as susceptible to changes in pH as less acidic soils such as brunisols.

° Acidic soils with a pH below 4.2 are sensitive to aluminum solubilization.

° Podzolic soils treated with acid rain simulants tend to adsorb added sulphate and nitrate becomes the mobile anion in leachates. Conversely, in natural forest soil systems, nitrate tends to be conserved in the soil and sulphate becomes mobile in drainage waters.

° Throughfall is enriched in nutrient and trace elements as compared to incident precipitation. Enrichment of $SO_4^{=}$ under conifers is greater than under hardwoods under similar atmospheric deposition. Enrichment of $SO_4^{=}$ in throughfall is higher in areas of higher atmospheric deposition.

° Conifers, as a rule, induce a pH depression of throughfall water while hardwood species elevate the pH. These changes are on the order of a tenth of a pH unit.

° Stemflow is even more enriched in nutrient ions and trace elements. As with throughfall, the species of the tree bole has an influence on the degree of this enrichment. Stemflow differences between conifers and hardwoods are highly pronounced. Conifer boles can depress incident precipitation pH by one half to one full pH unit. Hardwood boles have the opposite effect.

° Nitrogen compounds tend to be conserved by the tree canopy and bole, the reverse trend of other nutrient ions.

° Sulphate concentrations in soil leachate are elevated following rain episodes which follow prolonged dry periods, possibly resulting from sulphur oxidation in the soil during the dry period.

° The soil at the Muskoka sugar maple sites was acidic and contained high amounts of soluble aluminum.

° Declining sugar maple trees in Muskoka suffered extensive root death and the fine roots had significantly higher aluminum concentrations than fine roots of healthy trees.

- Incremental growth in the declining tree population appeared to be falling relative to the healthy trees for 20 years prior to caterpillar infestation.

- Acidic precipitation is considered to be an additional stress to the severe insect attacks and the spring droughts. Armillaria mellea root rot, tree age and site management are also contributing factors.

APPENDIX I

INTERNATIONAL LRTAP PROJECTS - MOE CO-FUNDING

Project Title	Funding Agencies	Purpose
Acid Deposition and Oxidants Model (Super Model)	Environment Ontario Atmospheric Environment Service Umweltbundesamt (West Germany) Environment Québec State of Minnesota State of New York	To improve predictions of source/receptor relationships, i.e. what areas are affected by what sources?
Dry Deposition Intercomparison Measurements	Environment Ontario Atmospheric Environment Service Illinois State Water Survey National Aeronautical Establishment U.S. Department of the Interior National Oceanic and Atmospheric Administration Environmental Protection Agency Argonne National Laboratory Oregon State University	To improve quality control and comparability of Canada/U.S. results.
Rain Acidity Interlaboratory Study of Damage to Agricultural Crops	Environment Ontario Boyce Thompson Institute Argonne International Laboratory Corvallis Environmental Research Laboratory Oakridge National Laboratory Brookhaven National Laboratory	To measure the effects of different pH's on crops and to standardize techniques and procedures. Study has been completed. A similar study is being developed for exclusion canopy work.

Project Title	Funding Agencies	Purpose
Reversing Acidification in Norway - NIVA	Environment Ontario Norway Sweden Environment Canada United Kingdom	To test hypotheses on watershed sensitivity and to measure watershed response to reductions and increases in acid loadings. This issue has been recently raised by the U.S. E.P.A. as an impediment to designing a control program.

INTERNATIONAL LRTAP PROJECTS - MOE PARTICIPATION

Project Title	Participating Agencies	Purpose
Aluminum Biogeochemistry in Forested Watersheds	Electric Power Research Institute Environment Ontario Environment Canada United States West Germany Norway Sweden United Kingdom	To identify and quantify the release, transport and toxicity of aqueous aluminum in the natural environment. Aluminum is toxic to both fish and trees.
Fisheries Loss Assessment Program	NAPAP Environment Ontario Ontario Ministry of Natural Resources EPRI Environment Canada	To assist NAPAP in the design of a program to assess fisheries loss in the U.S. related to acidic deposition.
Human Health Effects Related to Aquatic Effects of Acid Deposition	EPA Environment Ontario Various State Health Agencies	MOE has been invited to sit on a Committee of experts to determine the exact nature and extent of these human health effects.
Informal Calibrated Watershed Modelling Group	Environment Ontario Environment Canada United States Norway Sweden	To compare results and ideas on watershed studies. The work defines effects of acid rain and develops target loadings to prevent damage.

Project Title	Participating Agencies	Purpose
Interlaboratory Quality Assurance	Government and private laboratories in Canada and the U.S. (over 50 labs involved, including MOE)	To ensure the validity and compatibility of all data collected under LRT programs in North America.
Lake Acidification Mitigation Program	EPRI Clarkson College Environment Ontario	MOE has been requested to provide advice and information concerning lake liming projects.
National Surface Water Survey	EPA Environment Ontario Environment Canada	To characterize current water chemistry of lakes and streams in five U.S. Regions. MOE has been requested to assist in the development of the survey design.
Ontario/Minnesota Agreement	Ontario Minnesota	To exchange information on acid rain; to cooperate on specific projects (atmospheric modelling, RAIN - NIVA, aquatic effects in a medium deposition area).
Ontario/NADP Intercomparison Study - Ely, Minnesota	Ontario National Atmospheric Deposition Program	To improve comparability of data.

Project Title	Participating Agencies	Purpose
Ontario/New York Agreement	Ontario New York	To exchange information on acid rain; to cooperate on specific projects (deposition measurements and comparisons, possibly some mercury deposition and lake liming studies).

APPENDIX II

A.P.I.O.S. RELATED TECHNICAL REPORTS AND SUBMISSIONS

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1982 Daily Ambient Air Concentration Listings. APIOS Report No. 004/84.

1982 Daily Precipitation Chemistry Listings. APIOS Report No. 002/84.

An Overview of the Cumulative Wet/Dry Deposition Network. APIOS Report No. 007/84.

An Overview: The Cumulative Wet/Dry Deposition Network. W.H. Chan, D.B. Orr and R.J. Vet. APIOS Report No. 005/84.

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